Compact Athermal Filter in Silicon Waveguides for WDM and bio-sensing applications

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Abstract: We present a compact MZI on silicon platform with temperature sensitivity less than 0.2pm/K and total length around 100µm. It makes the device a promising candidate for wide range of WDM and bio-sensing applications.
OCIS codes: (230.5440) Polarization–selective devices; (230.7408) Wavelength filtering devices

1. Introduction

The fundamental limitations of silicon photonic devices are its high thermo-optic (TO) coefficient of silicon (1.86×10^{-4} K^{-1}). There are few solutions proposed, one of the approaches to use polymer over cladding which has negative TO coefficient [1]. But polymers introduce their own problems, such as aging and thermal hysteresis. Moreover, they cannot withstand high-temperature processes used in back-end metallizations. Another approach is to use local heaters to dynamically stabilize the device but this approach is power hungry.

The effective refractive index of a waveguide is a function of width (w), height (h), wavelength (λ) and temperature (T). It has already been shown that a Mach-Zender interferometer (MZI) can be made athermal [2], by choosing appropriate arm lengths the temperature sensitivity of both the arms to cancel each other out. This relies on the fact that the thermo-optic coefficient of one arm is somewhat different than that of the other, because of a different optical confinement in the silicon core. To accomplish this, very narrow waveguides with a low confinement can be used. But the problem with this approach is either the device size is large [2] or the very narrow waveguides which are too lossy [3]. To remediate this, we propose to use the TM polarization of a somewhat broader waveguide because the TM light is much less confined in the waveguide than the fundamental TE mode, it will also experience a lower thermo-optic coefficient. The loss is also lower as the TM mode does not have high field intensities on the rough sidewalls.

Here we introduce a compact MZI temperature insensitive filter by exploiting both polarizations supported by the on-chip waveguides. For this, the MZI includes a splitter –polarization rotator (SPR) which splits the light into two parts and rotates one half. A schematic of Silicon (Si) waveguide with air cladding used in the simulations and its corresponding dispersion behavior is shown in figure 1. The height of the Si waveguide was maintained at 220 nm and the cladding was air. Finite element method has been used for Eigen mode problem.

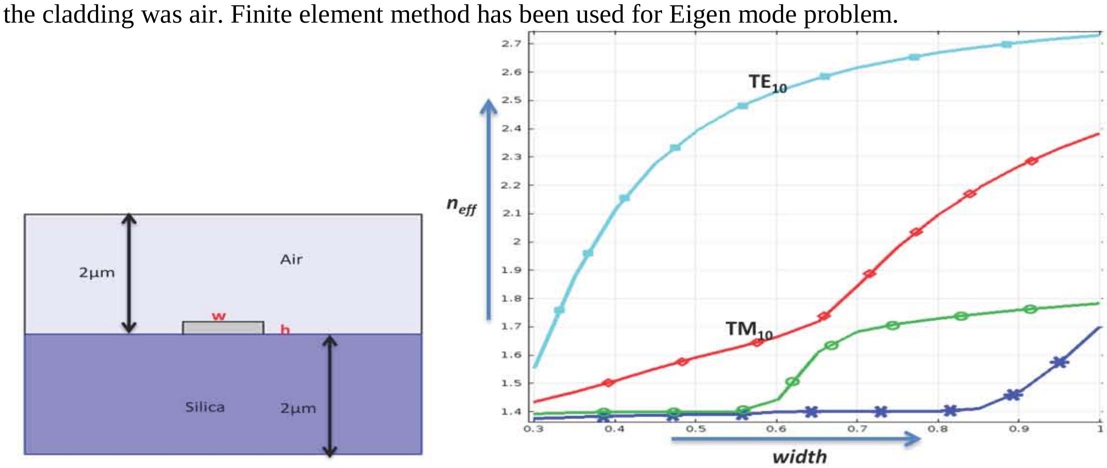

Figure 1. (a) Schematic of Si waveguide design with width w and height h and (b) effect of width variation on the effective index of the waveguide.

2. Methodology

The proposed structure is shown in figure 2. The input transverse electric (TE) polarized light passes through the SPR that splits and converts it into 50 % transverse magnetic (TM) in the upper arm and the remaining 50 %

remains in the lower arm as TE polarized light. Finally, they combine at output using a similar SPR as a combiner as shown in figure 2. There are adiabatic tapers connected from narrow to wider sections and vice-versa at both input and output ends as shown in figure 2.

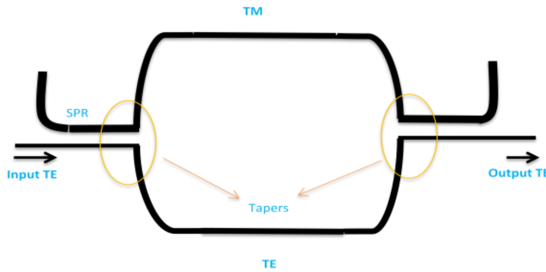

Figure 2. Schematic of proposed MZI

For the standard MZI, the condition for constructive interference is:

$$m\lambda = n_{eff}\Delta L \qquad (1)$$

with m an integer. For destructive interference, m should be a half integer. n_{eff} is the effective index of the waveguide and ΔL is path length difference at a given wavelength λ. For the proposed design we used different waveguides and different modes in both arms, so Eq. 1 is modified:

$$m\lambda = n_{eff_{TM}}.L1 - n_{eff_{TE}}.L2 \qquad (2)$$

$$M = m - \left(\frac{dn_{eff_{TM}}}{d\lambda}.L1 - \frac{dn_{eff_{TE}}}{d\lambda}.L2\right) \qquad (3)$$

Here L1 and L2 are the lengths of the corresponding arms for TE and TM polarized light, M is the modified interference due to the induced dispersion due to the difference in effective indices in the corresponding arms. The shift of constructive/destructive interference wavelength will now shift with temperature T as

$$\frac{d\lambda}{dT} = \left(\frac{dn_{eff_{TM}}}{dT}.L1 - \frac{dn_{eff_{TE}}}{dT}.L2\right)/M \qquad (4)$$

The objective for an athermal filter is to minimize the $d\lambda/dT$ and by doing so we can calculate the corresponding lengths L1 and L2. We can see that the larger the difference between the dn/dT of the two arms, the smaller will be the footprint of the device. In all the simulation the n_{eff} of silicon is taken as 3.48 and it's TO coefficient is 1.86×10^{-4} K^{-1} and for underlying SiO_2 it is 1.45 and 1×10^{-5} K^{-1}, respectively.

The waveguide width used for both TE and TM polarization in the upper and lower arms was 450 nm. The width was chosen to maintain the single mode operation and fabrication tolerant (wider) waveguide section. The adiabatic tapers are connected from SPR to the waveguide sections and are included in the device simulation. The n_{eff} is 2.28 for TE and 1.55 for TM as given in figure 1 and their calculated TO coefficients are 2.19×10^{-4} K^{-1} and 9.61×10^{-5} K^{-1}, respectively.

Figure 3 (a) shows the SPR design in which the input is TE that splits into TM in the wider section due to the phase matching condition and asymmetric structure. The phase matching condition is fulfilled with 320 nm narrow TE waveguide and 600 nm TM waveguide at which $n_{eff\_TE} = n_{eff\_TM} = 1.65$ as given in figure 1. Figure 3(b) and 3(c) showed the intensity profile and the coupling length (L_c) with respect to power transfer.

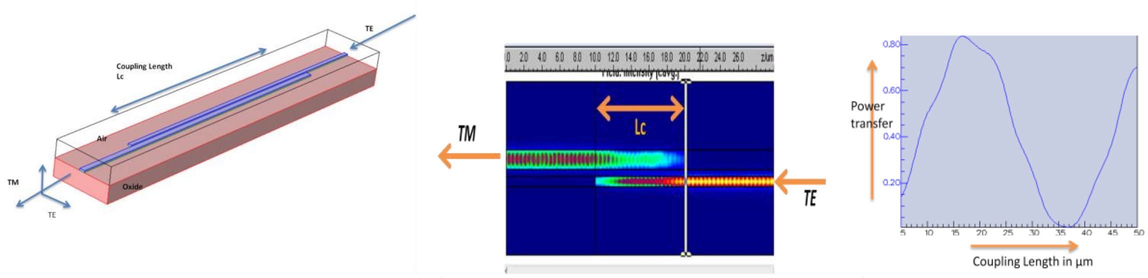

Figure 3. (a) SPR design (b) Intensity profile with respect to the length and (c) Power transfer with coupling length Lc

The gap between the waveguides was kept constant as 200 nm. As seen in the figure 3(c) the 50 % power transfer from TE to TM takes place at Lc = 10.1 µm

3. Result and Discussions

For m = 50, the calculated length of TM section for a given TE section (L2 = 20µm) is shown in figure 4 (a). The corresponding modified interference plot M is shown in figure 4(b).

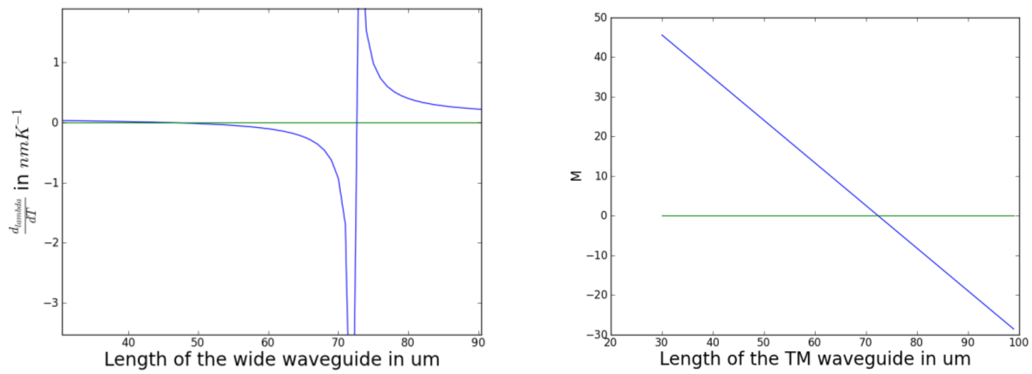

Figure 4. (a) The temperature insensitive point at 45.6 µm and (b) modified interference M

The asymptotic behavior of dλ/dT with length (fig. 4(a)) can be attributed to the zero crossing of M as shown in fig 4(b). The path length difference here is around 25.6 µm and the FSR is 41.2 nm. The normal uncompensated MZI made only from TM waveguide in both the arms, and the proposed temperature insensitive design due to TM and TE waveguides is shown in the figure 5 (a) and 5(b), respectively.

The simulated result shows the improvement from 80 pm/K drift to less than 0.2 pm /K. The results shown in figure 5 are for 0, 50 and 100 ^{0}C temperatures, respectively. The in-house circuit simulator Caphe [4] was used for the analysis and filter response of the presented device.

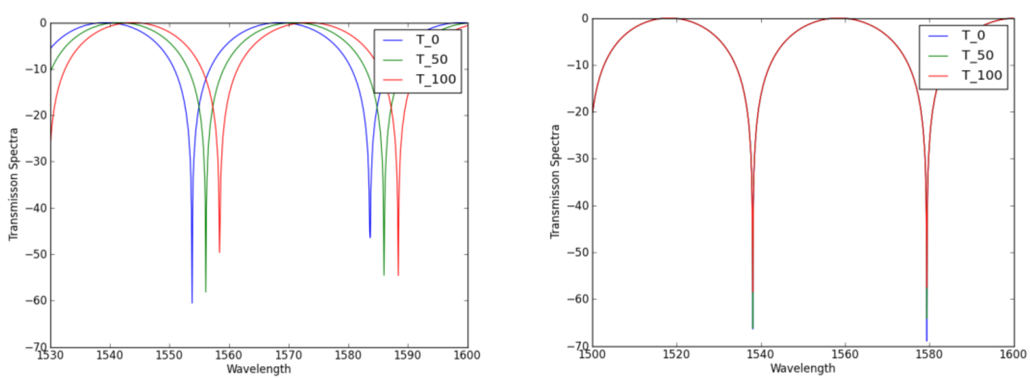

Figure 5. Transmission spectra (a) Uncompensated MZI for 0, 50 and 100 ^{0}C and (b) Temperature insensitive MZI filter

To conclude, we have introduced for the first time a compact athermal filter with total length of the device is less than 100µm a thermal drift of less than 0.2 pm /K. By the use of the TM polarization and an SPR the device provides a fabrication tolerant design due to flexibility in choosing wider waveguide sections. The device opens a choice for wider applications in WDM and bio-sensing where thermal behavior hinders and effects the performance.

4. References

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